US008385995B2

(12) **United States Patent**
Al-Ali et al.

(10) **Patent No.: US 8,385,995 B2**
(45) **Date of Patent: Feb. 26, 2013**

(54) **PHYSIOLOGICAL PARAMETER TRACKING SYSTEM**

(75) Inventors: **Ammar Al-Ali**, Tustin, CA (US); **Mohamed Diab**, Mission Viejo, CA (US); **Walter M. Weber**, Laguna Hills, CA (US)

(73) Assignee: **Masimo Corporation**, Irvine, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1604 days.

(21) Appl. No.: **11/834,602**

(22) Filed: **Aug. 6, 2007**

(65) **Prior Publication Data**

US 2008/0027294 A1 Jan. 31, 2008

Related U.S. Application Data

(63) Continuation of application No. 10/930,048, filed on Aug. 30, 2004, now Pat. No. 7,254,431.

(60) Provisional application No. 60/498,749, filed on Aug. 28, 2003.

(51) **Int. Cl.**
A61B 5/1455 (2006.01)

(52) **U.S. Cl.** **600/310**; 600/322; 600/323

(58) **Field of Classification Search** 600/309, 600/310, 322, 323, 324, 326, 330, 331, 336, 600/301
See application file for complete search history.

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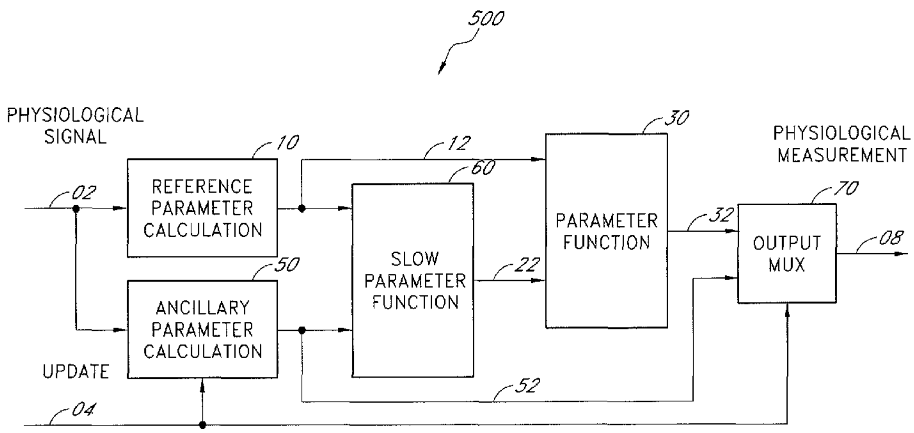
Primary Examiner — Eric Winakur
Assistant Examiner — Chu Chuan (JJ) Liu
(74) *Attorney, Agent, or Firm* — Knobbe, Martens Olson & Bear LLP

(57) **ABSTRACT**

A physiological parameter tracking system has a reference parameter calculator configured to provide a reference parameter responsive to a physiological signal input. A physiological measurement output is a physiological parameter derived from the physiological signal input during a favorable condition and an estimate of the physiological parameter according to the reference parameter during an unfavorable condition.

5 Claims, 5 Drawing Sheets



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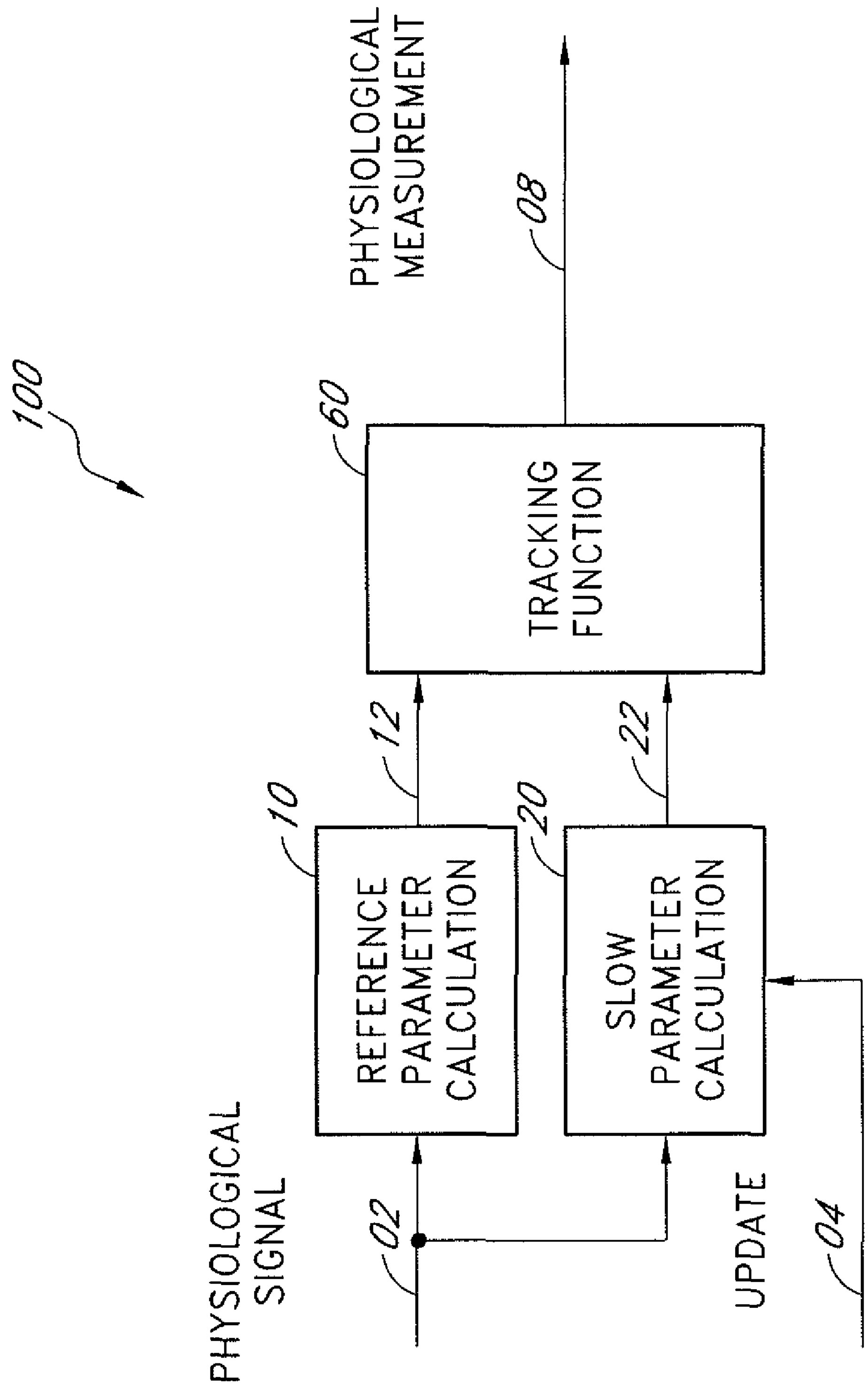
100
PHYSIOLOGICAL SIGNAL
02
REFERENCE PARAMETER CALCULATION
10
12
SLOW PARAMETER CALCULATION
20
22
UPDATE
04
TRACKING FUNCTION
60
08
PHYSIOLOGICAL MEASUREMENT

FIG. 1

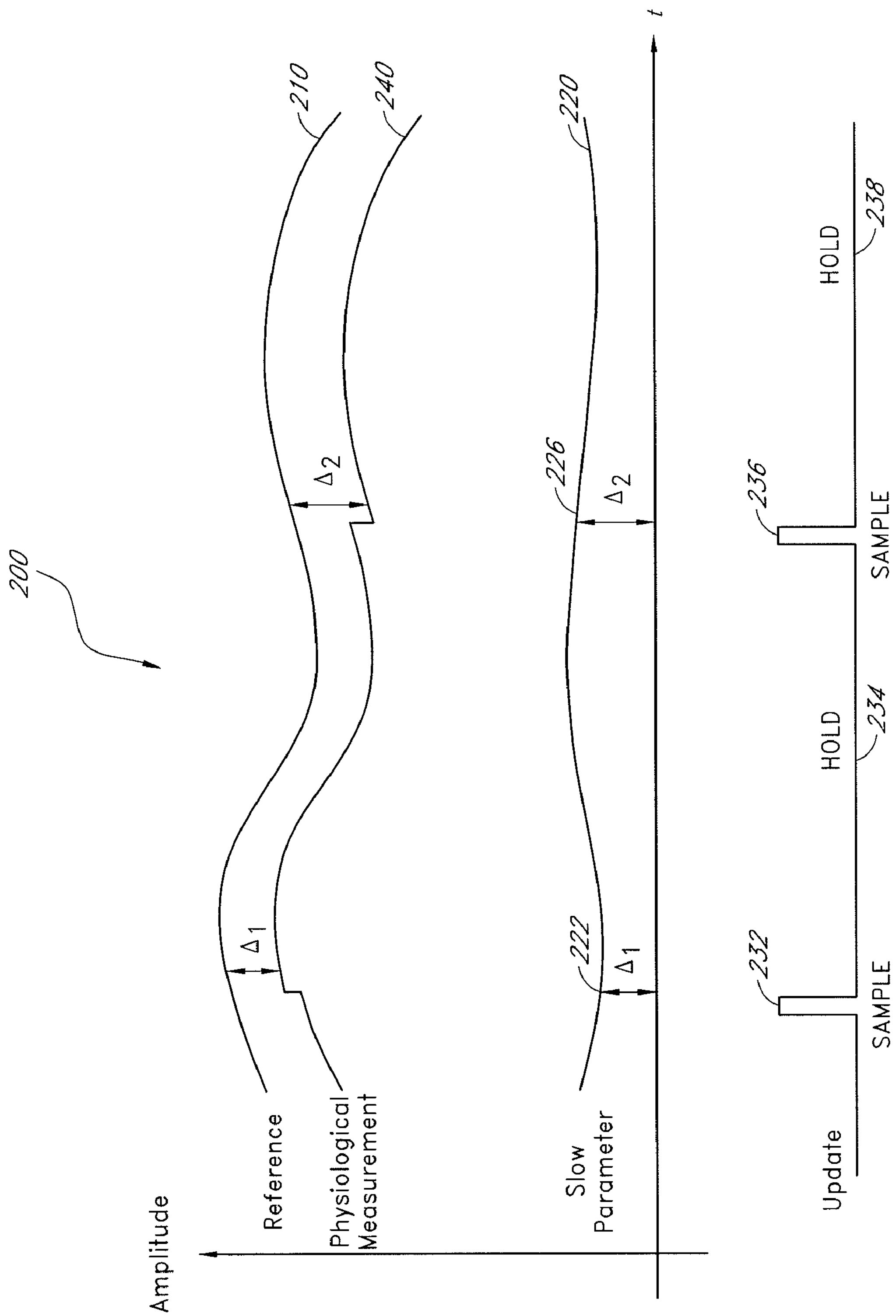
200
Amplitude
Reference
Physiological Measurement
Slow Parameter
Update
210
240
220
222
226
232
234
236
238
Δ1
Δ2
SAMPLE
HOLD
SAMPLE
HOLD
t

FIG. 2

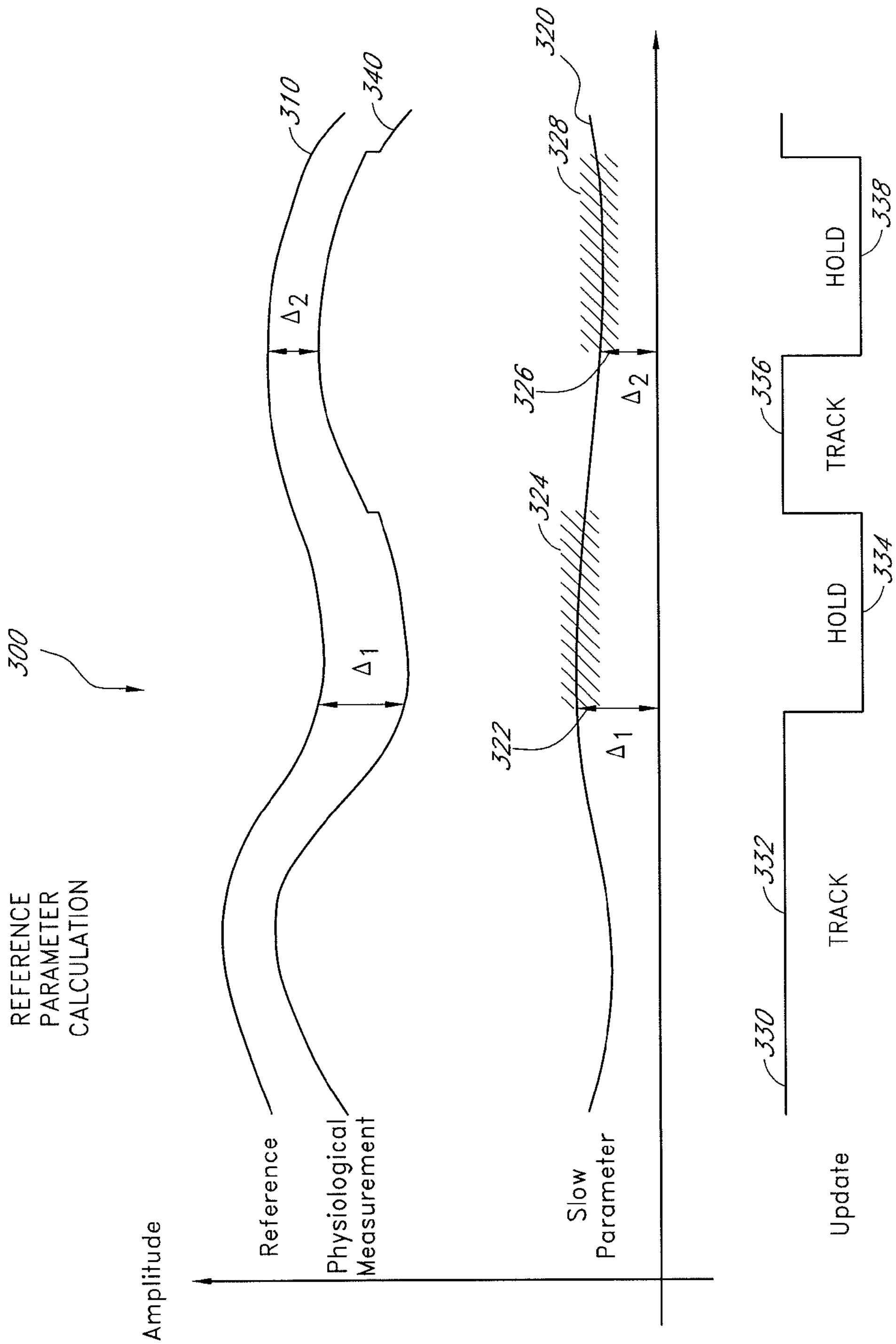
300
REFERENCE
PARAMETER
CALCULATION
Amplitude
Reference
Physiological
Measurement
Slow
Parameter
Update
310
340
320
322
324
326
328
330
332
334
336
338
Δ1
Δ2
Δ1
Δ2
TRACK
HOLD
TRACK
HOLD

FIG. 3

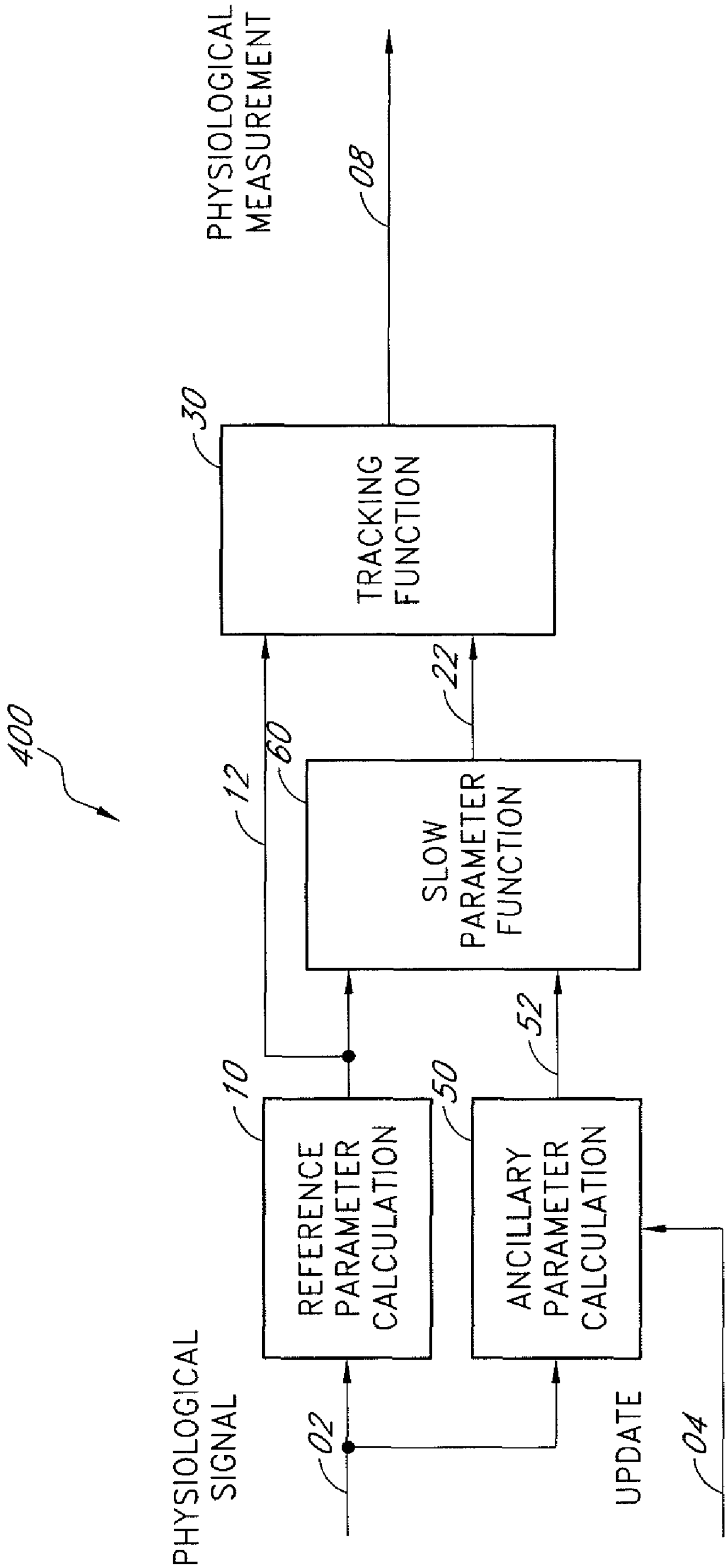
400
PHYSIOLOGICAL SIGNAL
02
UPDATE
04
REFERENCE PARAMETER CALCULATION
10
ANCILLARY PARAMETER CALCULATION
50
52
12
60
SLOW PARAMETER FUNCTION
22
30
TRACKING FUNCTION
08
PHYSIOLOGICAL MEASUREMENT

FIG. 4

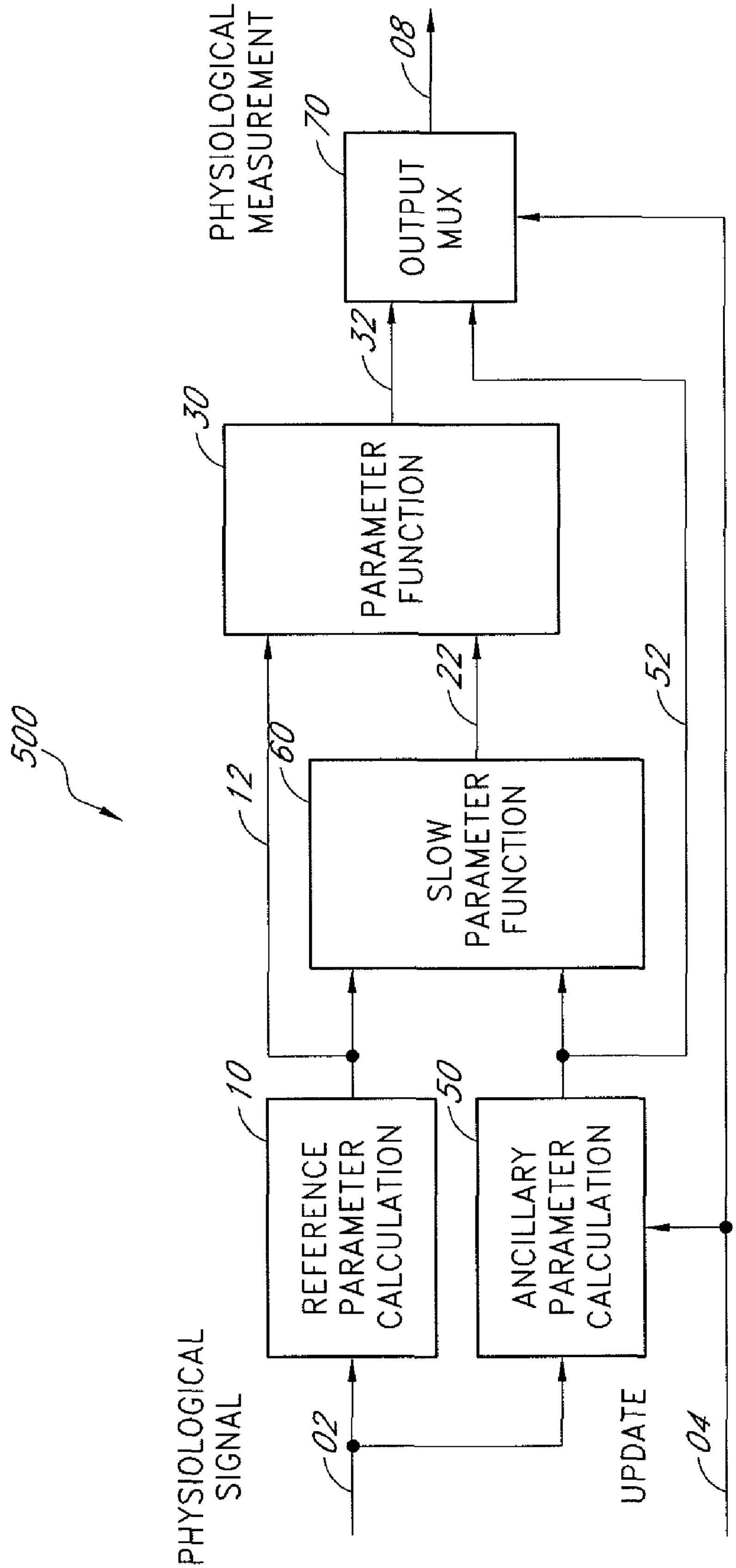
500
PHYSIOLOGICAL SIGNAL
02
UPDATE
04
REFERENCE PARAMETER CALCULATION
10
ANCILLARY PARAMETER CALCULATION
50
12
60
SLOW PARAMETER FUNCTION
22
52
PARAMETER FUNCTION
30
32
OUTPUT MUX
70
08
PHYSIOLOGICAL MEASUREMENT

FIG. 5

PHYSIOLOGICAL PARAMETER TRACKING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is continuation of U.S. patent application Ser. No. 10/930,048 filed Aug. 30, 2004, which claims the benefit of U.S. Provisional Patent Application 60/498,749, titled "Physiological Parameter Tracking System" filed Aug. 28, 2003. The present application incorporates the above-cited patent application and provisional patent application herein by reference.

BACKGROUND OF THE INVENTION

Oxygen transport from the lungs to body tissue can be monitored by measuring various physiological parameters. For example, oxygen saturation of arterial blood (S_aO_2) is a measure of the ratio of oxyhemoglobin (HbO_2) concentration to the sum of HbO_2 and deoxyhemoglobin (Hb) concentrations in the arterial blood. Because HbO_2 is the major oxygen carrying component of blood, S_aO_2 is indicative of oxygen delivery to body tissues. As another example, oxygen saturation of venous blood (S_vO_2) is a similar measure of HbO_2 and Hb concentrations in venous blood and is indicative of oxygen consumption by body tissues. Measurements of the concentrations of carboxyhemoglobin (HbCO) and methemoglobin (MetHb) are indicative of abnormal hemoglobin constituents that interfere with oxygen transport.

Pulse oximetry is a noninvasive, easy to use, inexpensive procedure for measuring the oxygen saturation level of arterial blood. Pulse oximeters perform a spectral analysis of the pulsatile component of arterial blood in order to determine oxygen saturation ($S_{pa}O_2$), which is an estimate of S_aO_2. A pulse oximetry system has a sensor and a monitor. The sensor has emitters that typically consist of a red light emitting diode (LED) and an infrared LED that project light through blood vessels and capillaries underneath a tissue site, such as a fingernail bed. A sensor also has a detector that typically is a photodiode positioned opposite the LEDs so as to detect the emitted light as it emerges from the tissue site. A pulse oximetry sensor is described in U.S. Pat. No. 6,088,607 entitled "Low Noise Optical Probe," which is assigned to Masimo Corporation, Irvine, Calif. and incorporated by reference herein.

SUMMARY OF THE INVENTION

One aspect of a physiological parameter tracking system comprises a physiological signal and first, second, third and fourth calculators. The physiological signal has at least first and second intensity signal components received from a light-sensitive detector that detects light of at least first and second wavelengths transmitted through body tissue carrying pulsing blood. The first calculator is configured to output a reference parameter responsive to the physiological signal. The second calculator is configured to output an ancillary parameter responsive to the physiological signal. The third calculator is configured to output a slow parameter that is a function of the reference parameter and the ancillary parameter. The slow parameter is a function of time that is slowly varying relative to the reference parameter and the ancillary parameter. A fourth calculator is configured to output a physiological measurement responsive to the reference parameter and the slow parameter. In an embodiment, the fourth calculator provides a physiological measurement that is at least in part a function of the reference parameter and the slow parameter.

In an embodiment, the physiological measurement is a function of the reference parameter and the slow parameter during a first time interval and is the ancillary parameter during a second time interval. In an embodiment, the first time interval includes a period when calculations of the ancillary parameter are unfavorable. In an embodiment, the second time interval includes a period when calculations of the ancillary parameter are favorable.

Another aspect of a physiological parameter tracking system comprises inputting a physiological signal, deriving a physiological measurement from the physiological signal during a favorable condition, estimating the physiological measurement during an unfavorable condition and outputting a combination of the derived physiological measurement and the estimated physiological measurement. In an embodiment, estimating comprises calculating a slow parameter that is physiologically related to the reference parameter and the physiological measurement and tracking the reference parameter with the slow parameter. In an embodiment, outputting comprises selecting between estimated physiological measurement and derived measurement according to the favorable condition and the unfavorable condition. In an embodiment, the favorable condition and the unfavorable conditions relate to power consumption goals. In an embodiment, the favorable condition and the unfavorable conditions relate to the quality of the physiological signal.

A further aspect of a physiological parameter tracking system comprises a physiological signal input, a reference parameter calculator and a physiological measurement means for outputting and estimating. The physiological signal input has at least first and second intensity signal components received from a light-sensitive detector that detects light of at least first and second wavelengths transmitted through body tissue carrying pulsing blood. The reference parameter calculator is configured to output a reference parameter responsive to the physiological signal. The physiological measurement means outputs a physiological parameter derived from the physiological signal input during a favorable condition and estimates the physiological parameter according to the reference parameter during an unfavorable condition. In an embodiment, a slow parameter means relates the reference parameter to the physiological parameter during the unfavorable condition. In an embodiment, an update means selects a first time period for outputting the derived physiological parameter and a second time period for outputting the estimated physiological parameter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a slow parameter calculation embodiment of a physiological parameter tracking system;

FIG. **2** is a graph illustrating operation of a physiological parameter tracking system in a sample and hold (S/H) mode;

FIG. **3** is a graph illustrating operation of a physiological parameter tracking system in a track and hold (T/H) mode;

FIG. **4** is a block diagram of an ancillary calculation embodiment of a physiological parameter tracking system for operation in a S/H mode; and

FIG. **5** is a block diagram of an ancillary calculation embodiment of a physiological parameter tracking system for operation in a T/H mode.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Overview

FIGS. **1**, **4** and **5** illustrate embodiments of a physiological parameter tracking system that advantageously provide a clinically accurate physiological measurement by tracking a reference parameter based upon a slowly varying ("slow") parameter. As such, it is not necessary to continuously or frequently perform complex calculations to derive the physiological measurement. That is, the physiological measurement is a relatively simple function of the reference parameter and the slow parameter. Slow parameter calculations are performed only when conditions are favorable, or alternatively, suspended when conditions are not favorable, as indicated by an update command. The update command may be responsive to conditions such as power consumption goals or the quality of a physiological signal input to name a few.

In one embodiment, the slow parameter is HbCO or MetHb, and the reference parameter is $S_{pa}O_2$. Accordingly, the physiological measurement is $S_{pa}O_2$ corrected for the presence of one or both of these abnormal hemoglobin constituents. In another embodiment, the slow parameter is $\Delta_{av}=S_{pa}O_2-S_vO_2$, a measure of oxygen consumption at a tissue site, and the reference parameter is $S_{pa}O_2$. Accordingly, the physiological measurement is an estimate of S_vO_2.

Slow Parameter Calculation

FIG. **1** illustrates a slow parameter calculation embodiment of a physiological parameter tracking system **100** in which the slow parameter **22** is derived from and responsive to a physiological signal **02**. The physiological parameter tracking system **100** has a physiological signal **02** input, a reference parameter calculation **10**, a slow parameter calculation **20** and a tracking function **30** and generates a physiological measurement **08** output. The reference parameter calculation **10** generates a reference parameter **12** from the physiological signal **02**. The slow parameter calculation **20** generates the slow parameter **22** from the physiological signal **02** input. The tracking function **30** generates the physiological measurement **08** from the reference parameter **12** and the slow parameter **22**.

As shown in FIG. **1**, the physiological signal **02** is responsive to a physiological condition. In one embodiment, the physiological signal **02** originates from an optical sensor (not shown) attached to a tissue site. The sensor transmits multiple wavelengths of optical energy $\lambda_1, \lambda_2, \ldots, \lambda_n$ into the tissue site and detects corresponding optical energy emerging from the tissue site. The reference parameter calculation **10** may include pulse oximetry algorithms that operate on the physiological signal **02** to generate arterial oxygen saturation, $S_{pa}O_2$, as the reference parameter **12**. A pulse oximetry signal processor and algorithms are described in U.S. Pat. No. 5,632,272 entitled Signal Processing Apparatus which is assigned to Masimo Corporation, Irvine, Calif. and incorporated by reference herein.

Also shown in FIG. **1**, the slow parameter calculation **20** generates a slow parameter **22** from the physiological signal input **02** according to an update command **04**. As an example, the slow parameter calculation **20** may include algorithms that operate on the physiological signal **02** to generate a measure of the concentration of abnormal hemoglobin, such as HbCO or MetHb. Multiple wavelength signal processing for measuring abnormal hemoglobin constituents, for example, is described in U.S. Provisional Patent App. No. 60/426,638 entitled "Parameter Compensated Physiological Monitor," U.S. Provisional Patent App. No. 60/428,419 entitled "Blood Parameter Measurement System," and U.S. Pat. No. 6,229,856 entitled Method and Apparatus for Demodulating Signals in a Pulse Oximetry System, which is assigned to Masimo Corporation, Irvine, Calif., all incorporated by reference herein.

Further shown in FIG. **1**, the update command **04** may operate in a sample and hold (S/H) mode. That is, when the update command **04** is asserted, the slow parameter calculation **20** is triggered and the resulting slow parameter **22** value is held until a subsequent calculation. Operation of a physiological parameter tracking system having a S/H update is described with respect to FIG. **2**, below. Alternatively, the update command **04** may operate in a track and hold (T/H) mode. That is, while the update command **04** is asserted, the slow parameter calculation **20** continues to generate values for the slow parameter **22**. When the update command **04** is not asserted, the last generated value of the slow parameter **22** is held until the update command **04** is once more asserted. Operation of a physiological parameter tracking system having a T/H update is described with respect to FIG. **3**, below.

TRACKING EXAMPLES

FIG. **2** is an amplitude versus time graph **200** illustrating operation of a physiological parameter tracking system utilizing a S/H update. The graph **200** illustrates a reference curve **210** corresponding to a reference parameter **12** (FIG. **1**) and a slow parameter curve **220** corresponding to a slow parameter **22** (FIG. **1**). Below the graph **200** is a timing diagram **230** corresponding to the update command **04** (FIG. **1**). A physiological measurement curve **240** corresponds to the physiological measurement **08** (FIG. **1**).

As shown in FIG. **2**, the physiological measurement curve **240** tracks the reference curve **210** according to a tracking function **30** (FIG. **1**), which in this illustration is the difference between the reference parameter **12** (FIG. **1**) and the slow parameter **22** (FIG. **1**). A slow parameter **220** value is calculated at sample times **232**, **236** and maintained throughout hold periods **234**, **238**. In particular, during a first sample time **232**, a slow parameter value **222** of Δ_1 is calculated, and during a second sample time **236**, a slow parameter value **226** of Δ_2 is calculated. As a result, during a first hold period **234**, the physiological measurement curve **240** tracks the reference curve **210** by a difference of Δ_1. Likewise, during a second hold period **238**, the physiological measurement curve **240** tracks the reference curve **210** by a difference of Δ_2. In this manner, the physiological measurement **240** is advantageously displayed with clinical accuracy utilizing only occasional computational resources and reducing power consumption accordingly.

FIG. **3** is an amplitude versus time graph **300** illustrating operation of a physiological parameter tracking system utilizing a T/H update. The graph **300** illustrates a reference curve **310** corresponding to a reference parameter **12** (FIG. **1**) and a slow parameter curve **320** corresponding to a slow parameter **22** (FIG. **1**). Below the graph **300** is a timing diagram **330** corresponding to the update command **04** (FIG. **1**). A physiological measurement curve **340** corresponds to the physiological measurement **08** (FIG. **1**).

As shown in FIG. **3**, the physiological measurement curve **340** tracks the reference curve **310** according to a tracking function **30** (FIG. **1**), which, again, is the difference between the reference parameter **12** (FIG. **1**) and the slow parameter **22** (FIG. **1**). Slow parameter **320** values are calculated throughout track periods **332**, **336**, and the last computed values are maintained throughout the corresponding hold periods **334**, **338**. In particular, during a first track period **332**, the physiological measurement curve **340** is the reference curve **310** minus the slow parameter curve **320**. At the end of the first track period **332**, a slow parameter value **332** of Δ_1 is maintained throughout the first hold period **334**. As a result, during the first hold period **334**, the physiological measurement curve **340** is the reference curve **310** minus Δ_1 and does not depend on the slow parameter curve **320**. That is, during the first hold period **332**, the physiological measurement curve **340** tracks the reference curve **310** by a difference of Δ_1.

The "track" periods **332**, **336** are so named because the slow parameter calculation **20** (FIG. **1**) in response to the update timing **330** operates in a manner roughly analogous to a conventional track/hold amplifier when its output tracks the input. These are not to be confused with the periods when the physiological measurement curve **340** is "tracking" the reference parameter curve **310**, which actually is during the hold periods **334**, **338**, when the slow parameter **22** (FIG. **1**) output is held constant.

Also shown in FIG. **3**, during a second track period **336**, the physiological measurement curve **340** is again the reference curve **310** minus the slow parameter curve **320**. At the end of the second track period **336**, a slow parameter value **326** of Δ_2 is maintained throughout the second hold period **338**. As a result, during the second hold period **338**, the physiological measurement curve **340** is the reference curve **310** minus Δ_2 and does not depend on the slow parameter curve **320**. That is, during the second hold period **338**, the physiological measurement curve **340** tracks the reference curve **310** at a difference of Δ_2.

Further shown in FIG. **3**, the hold periods **334**, **338** may correspond to slow parameter drop-out periods **324**, **328**, i.e. periods when the slow parameter cannot be accurately calculated. In this manner, the physiological measurement **340** is advantageously displayed with clinical accuracy even when noise or other signal corruption prevents measurement of the slow parameter **320**.

Ancillary Parameter Calculation

FIG. **4** illustrates an ancillary parameter calculation embodiment of a physiological parameter tracking system **400** in which the slow parameter **22** is derived from an ancillary parameter **52** in S/H mode. The ancillary parameter **52**, in turn, is derived from a physiological signal **02**. That is, unlike the slow parameter calculation embodiment **100** (FIG. **1**), the slow parameter **22** is only indirectly derived from and responsive to the physiological signal **02**. The physiological parameter tracking system **400** has a physiological signal **02** input, a reference parameter calculation **10** and a tracking function **30**, and, accordingly, generates a physiological measurement **08**, similarly as described with respect to FIG. **1**, above. However, in the ancillary calculation embodiment **400**, the slow parameter **22** is a function **60** of the reference parameter **12** and/or an ancillary parameter **52**. An ancillary parameter calculation **50** generates the ancillary parameter **52** from the physiological signal input **02** according to a S/H update command **04** input, such as described with respect to FIG. **2**, above.

As an example, the ancillary parameter calculation **50** may include algorithms that operate on the physiological signal **02** to intermittently calculate venous oxygen saturation, $S_{pv}O_2$, as determined by a S/H update command **04**. A corresponding slow parameter function **60** is the difference between an $S_{pa}O_2$ reference parameter **12** and the $S_{pv}O_2$ ancillary parameter **52** to yield a Δ_{av} slow parameter **22**. Then, the tracking function **30** is a difference between the $SpaO_2$ reference parameter **12** and the sampled Δ_{av} slow parameter **22** to generate a $S_{pv}O_2'$ physiological measurement **08**. That is, the physiological measurement **08** in this example advantageously provides a continuous measurement of venous saturation $S_{pv}O_2'$ utilizing intermittent calculations of $S_{pv}O_2$. Apparatus and methods for determining $S_{pv}O_2$ from mechanical or ventillator induced perturbation of the venous blood volume are described in U.S. Pat. No. 5,638,816 entitled "Active Pulse Blood Constituent Monitoring" and U.S. Pat. No. 6,334,065 entitled "Stereo Pulse Oximeter," which are assigned to Masimo Corporation, Irvine, Calif. and are incorporated by reference herein.

FIG. **5** illustrates an ancillary parameter calculation embodiment of a physiological parameter tracking system **500** in which the slow parameter **22** is derived from an ancillary parameter **52** in T/H mode. The ancillary parameter **52**, in turn, is derived from a physiological signal **02**. The physiological parameter tracking system **500** has a physiological signal **02** input, a reference parameter calculation **10**, an ancillary parameter calculation **50**, a slow parameter function **60** and a tracking function **30**, and, accordingly, generates a physiological measurement **08**, similarly as described with respect to FIG. **4**, above. However, in this ancillary calculation embodiment **500**, the update command **04** operates in a track and hold mode, as described with respect to FIG. **3**, above. Accordingly, the ancillary calculation embodiment **500** also has an output multiplexer **70** having the tracking function output **32** and the ancillary parameter **52** as inputs and the physiological measurement **08** as an output, as controlled by the update command **04** input. As such, the physiological measurement **08** is the ancillary parameter **52** during a track period **332**, **336** (FIG. **3**) of the update command **04** and is a function of the ancillary parameter **52** and the reference parameter **10** during a hold period **334**, **338** (FIG. **3**) of the update command **04**. That is, the physiological measurement **08** is advantageously the ancillary parameter **52** except during a hold period, when the physiological measurement **08** tracks the reference parameter **12** according to the maintained value of the slow parameter **22**.

As an example, the ancillary parameter calculation **50** may continuously calculate venous oxygen saturation, $S_{pv}O_2$, as determined by the update command **04** during track periods, and this calculation is provided as the physiological measurement **08**. However, during hold periods of the update command **04**, the physiological measurement **08** becomes $S_{pv}O_2'$, i.e. the $S_{pa}O_2$ reference parameter **12** minus a maintained value of the Δ_{av} slow parameter **22**. The physiological measurement **08** in this example advantageously provides a measurement of venous saturation that is continuous through drop-out periods.

A physiological parameter tracking system has been disclosed in detail in connection with various embodiments. These embodiments are disclosed by way of examples only and are not to limit the scope of the claims that follow. One of ordinary skill in the art will appreciate many variations and modifications.

What is claimed is:

1. A physiological parameter tracking system comprising:

a physiological signal input having at least first and second intensity signal components received from a light-sensitive detector that detects light of at least first and second wavelengths transmitted through body tissue carrying pulsing blood;

a first calculator configured to output a reference parameter responsive to the physiological signal;

a second calculator configured to output an ancillary parameter responsive to the physiological signal;

a third calculator configured to output a slow parameter that is a function of the reference parameter and the ancillary parameter and is slowly varying in time relative to the reference parameter and the ancillary parameter; and

a fourth calculator configured to output a physiological measurement responsive to the reference parameter and the slow parameter, wherein the fourth calculator provides a physiological measurement that is at least in part of a function of the reference parameter and the slow parameter and wherein the physiological measurement is a function of the reference parameter and the slow parameter during a first time interval and is the ancillary parameter during a second time interval.

2. The physiological parameter tracking system according to claim **1** wherein the first time interval includes a period when calculations of the ancillary parameter are unfavorable.

3. The physiological parameter tracking system according to claim **2** wherein the second time interval includes a period when calculations of the ancillary parameter are favorable.

4. A physiological parameter tracking system comprising:

a physiological signal input having at least first and second intensity signal components received from a light-sensitive detector that detects light of at least first and second wavelengths transmitted through body tissue carrying pulsing blood;

a reference parameter calculator configured to output a reference parameter responsive to the physiological signal;

means for outputting a physiological parameter derived from the physiological signal input during a favorable condition and estimating the physiological parameter according to the reference parameter during an unfavorable condition;

means for relating the reference parameter to the physiological parameter during the unfavorable condition; and

means for selecting a first time period for outputting the derived physiological parameter and a second time period for outputting the estimated physiological parameter.

5. A physiological parameter tracking system comprising:

a physiological signal input having at least first and second intensity signal components received from a light-sensitive detector that detects light of at least first and second wavelengths transmitted through body tissue carrying pulsing blood;

a reference parameter calculator configured to output a reference parameter responsive to the physiological signal;

a physiological measurement calculator configured to output a physiological parameter derived from the physiological signal input during a favorable condition and estimating the physiological parameter according to the reference parameter during an unfavorable condition;

a slow parameter calculator configured to relate the reference parameter to the physiological parameter during the unfavorable condition; and

an update processor configured to select a first time period for outputting the derived physiological parameter and a second time period for outputting the estimated physiological parameter.

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